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**Seeing is believing: Communication  
performance under isotropic  
teleconferencing conditions**

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title

## Seeing is believing: Communication performance under isotropic teleconferencing conditions

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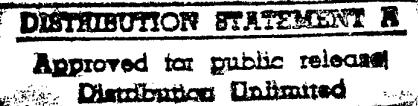
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Videoconferencing is een sterk opkomende tele-communicatietechniek die het mogelijk maakt om op afstand te communiceren, waarbij non-verbale beeldinformatie (gezichtsuitdrukkingen, gebaren, houding, etc.) wordt uitgewisseld. Afhankelijk van het type communicatieproces kan non-verbale informatie een belangrijke meerwaarde hebben. Videoconferencing kan vergaderingen en diensten via electronische weg laten verlopen waarmee reiskosten en arbeidstijd bespaard wordt. Voor succesvolle toepassing is het echter belangrijk om kennis te hebben over hoe videoconferencing het gedrag en de prestaties van gebruikers verandert ten opzichte van face-to-face situaties (fysiek bijeen komen).

Het hier beschreven onderzoek had tot doel om inzicht te krijgen in hoe onderliggende aspecten van communicatieprocessen (overtuigingskracht, dominantie, informatie-uitwisseling, groepsbelang) veranderen door toepassing van multi-point videoconferencing technieken.

Er zijn drie vergader condities onderzocht. De eerste, *niet-isotroop* videovergaderen, is de huidige beschikbare videovergadertechniek waarbij participanten elkaar via een enkele monitor en een enkele camera per telewerkplek kunnen zien. Hierbij kijkt iedereen dus naar iedereen en is geen gerichte blik mogelijk. De tweede is *isotroop* videovergaderen waarbij drie participanten elkaar via een telewerkplek, uitgerust met meerdere camera's en monitoren, kunnen zien in ruimtelijk consistente richtingen (gemeenschappelijke videoruimte). De derde conditie is face-to-face vergaderen (fysiek rond de tafel).

Zowel het interactie proces en de resultaten van verschillende discussie taken zijn onderzocht voor de drie vergadercondities. De communicatie van verdeelde informatie is getest in een moordzaak, de zogenaamde 'Case of the Fallen Businessman'. Dominantie en overtuiging zijn getest in het onderhandelingsspel 'Lost at the Moon' waaraan een dominante acteur deelnam. Tenslotte zijn emotioneel gedrag en de afweging tussen individueel en groepsbelang gekwantificeerd met een "prisoner's dilemma"-achtig management spel.

De resultaten laten onder meer zien dat overtuigingskracht (het vermogen andermans mening te veranderen) significant sterker is onder isotrope communicatiecondities (inclusief face-to-face) dan onder niet-isotrope condities. Daarentegen is dominantie (het vermogen om de groepsoplossing te beïnvloeden door dominant gedrag) gelijk in alle condities. Verder wisselen de proefpersonen twee maal zoveel verdeelde informatie uit en hechten zij meer waarde aan het groepsbelang in videocondities dan in de face-to-face conditie.

De experimenten bestonden uit een beperkte selectie van generieke taken onder laboratoriumomstandigheden. Daarom is voorzichtigheid geboden met het interpreteren van deze resultaten en met het inschatten van de mogelijke waarde voor verschillende toepassingen van videovergaderen. Het verdient aanbeveling om specifieke toepassingen grondig te evalueren met betrekking tot menselijk functioneren om zowel meerwaarde als knelpunten explicet te maken.

Toekomstig onderzoek zou zich moeten richten op nog onbeantwoorde vragen zoals bijvoorbeeld de invloed van groepsgrootte, gebruiksduur, beeldkwaliteit en transmissiedelays op het videovergaderproces.

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## SUMMARY

The visual component of conversational media such as video-conferencing systems communicates important non-verbal information such as facial expressions, gestures, posture and gaze. Unlike the other cues, selective gaze depends critically on the configuration of cameras and monitors. Under isotropic video conferencing conditions people see each other in spatially consistent directions (shared video space). Isotropy is hypothesized to improve the interactional process of conversation and the outcome of discussion tasks compared to non-isotropic conditions.

We have studied the interactional process and task outcome of a variety of discussion tasks under isotropic and (standard) non-isotropic video-conferencing conditions relative to face-to-face conditions. The communication of unshared information was tested in a murder-solving task called "The Case of the Fallen Businessman". Dominance and persuasive force were revealed using a prioritization game of survival items called "Lost at the moon", featuring a dominant actor. Further, we quantified emotional behavior and the trade-off between individual and group benefits in a "prisoner's dilemma"-like management game.

The results support our hypotheses and have revealed that persuasive force (the ability to change another person's opinion) is significantly stronger under isotropic conditions (including face-to-face) than under non-isotropic conditions. In contrast, dominance (the ability to influence group solutions by dominant behavior) is similar for all conditions. Further, participants communicate almost twice as much unshared information and value group benefit far more under mediated conditions than under the face-to-face condition.

**Zien doet geloven: communicatieprestaties onder isotrope televergadercondities**

P.J. Werkhoven, P.A.J. Punte, J.M.C. Schraagen en E.R. Spoelma

**SAMENVATTING**

De visuele component van communicatiemedia zoals video-conferencing systemen brengt veel non-verbale informatie over zoals gezichtsuitdrukkingen, gebaren, houding en kijkgedrag. In tegenstelling tot de andere componenten is de kijkrichting afhankelijk van de configuratie van camera's en monitoren. In de isotrope videoconditie kunnen de proefpersonen elkaar zien in ruimtelijk consistente richtingen (gemeenschappelijke videoruimte). Er wordt verondersteld dat isotropie het interactie proces en de prestatie van de discussietaken verbetert ten opzichte van de niet-isotrope systemen.

Het interactieproces en de resultaten van verschillende discussie taken is onderzocht in een isotrope en een niet-isotrope (standaard) video-conferencing conditie in vergelijking met een face-to-face conditie. De communicatie van verdeelde informatie is getest in een moordzaak, de zogenaamde 'Case of the Fallen Businessman'. Dominantie en overtuiging zijn getest in het onderhandelingsspel 'Lost at the Moon' waaraan een dominante acteur deelnam. Tenslotte is emotioneel gedrag gekwantificeerd en de afweging tussen individueel en groepsbelang in een "prisoner's dilemma"-achtig management spel.

De resultaten ondersteunen de hypotheses en tonen aan dat overtuigingskracht (het vermogen andermans mening te veranderen) significant sterker is onder isotrope communicatiecondities (inclusief face-to-face) dan onder niet-isotrope condities. Daarentegen is dominantie (het vermogen om de groepsoplossing te beïnvloeden door dominant gedrag) gelijk in alle condities. Verder wisselen de proefpersonen twee maal zoveel verdeelde informatie uit en hechten zij meer waarde aan het groepsbelang in gemedieerde condities dan in de face-to-face conditie.

## 1 INTRODUCTION

When people meet in a shared physical space they are able to exchange enormous amounts of information carried by sound (speech), light (gaze, facial expressions, gestures, posture, physical appearance), chemicals (smell) or by direct contact (touch). In a shared physical space the communication bandwidth is only limited by our senses, not by the medium.

Modern telecommunication techniques (such as tele-conferencing) allow people to meet virtually, which might eliminate the necessity to physically get together. Both auditory and visual communication can now be mediated by electronic audio and video signals across world-wide networks. The advantages of not having to travel, in terms of expenses and time-efficiency, are evident. The bandwidth of current mediated communication, however, is *limited*. Because of this limitation the richness of video information in particular has been reduced in the spatial dimension (the size and quality of images) as well as in the temporal dimension (transmission delays and update frequencies).

Human factors researchers are challenged to understand the pros and cons of impoverished visual communication (carrying non-verbal information) during mediated interaction with respect to human behavior and task performance.

Current video-conferencing systems deal with a limited bandwidth of the video-channel by either squeezing minified images of all participants on a single monitor, or by presenting the full-sized image of only a single (speaking) participant. Further, each participant generally looks at a single monitor and is sensed by a single camera. Both options filter out natural non-verbal information such as the viewing directions (gaze) of participants relative to the others. This may seriously affect human interaction and task-performance because eye-contact often regulates the conversation by directing the supply and demand of information and by increasing the intensity of the conversation. It is worthwhile, therefore, to investigate video-conferencing systems that do not filter out eye-contact and viewing direction.

We have studied the benefits of a multi-party video-conferencing system in which participants see each other in spatially consistent directions, that is, in a shared virtual space. We call this an *Isotropic video COnferencing System* (ICOS) because the conferencing space conserves the 3D directional properties of gaze for all participants. The performance of participants during a variety of discussion tasks under isotropic video-conferencing was compared with non-isotropic video-conferencing and face-to-face conditions.

### 1.1 What is known about communication under teleconferencing conditions?

Non-verbal visual communication includes gaze, facial expressions, gesture and posture. Non-verbal behavior has naturally evolved, strongly suggesting that it has important functions such as regulating, completing or even substituting verbal communication. For example, selective gaze is thought to support the regulation and synchronization of conversation (e.g., taking and avoiding the floor and suggesting who should speak next (see Argyle & Cook, 1976; Kendon,

1967). Further, gaze is thought to provide feedback on how the listener perceives a verbal message (e.g., understanding, disinterest) or by communicating emotions (e.g., enthusiasm, anger).

Because these assumptions are intuitively convincing, one might expect researchers to have found evidence supporting these assumptions. The contrary is true, however. Research seems to show that the presence of a video channel in addition to an audio channel has no effect on the performance of tasks that are highly independent of social cues. Only when social cues become relevant (e.g., equivocal situations as conflicts and bargaining) visual communication may influence the task outcome (Short, Williams & Christie, 1976; Daft & Lengel, 1986).

Because no overwhelming effects have been found in previous studies, Sellen (1995) has focussed, not on task performance, but on the interactional process of conversation (speaker turns, interruptions, etc.) as a way of assessing the effect of a conversational medium. The effect of reduced visual cues on the interactional process had been studied by others but with questionable and inconsistent results and comparing only face-to-face situations with audio-only for dyadic conversation (see Sellen, 1995). Sellen used objective measures to show that under the face-to-face condition people produce significantly more interruptions and fewer formal handovers of the floor than in any mediated condition (audio-only and video-conferencing conditions). Effects of the type of video-conferencing (isotropic versus non-isotropic), however, were not significant.

The inconsistent or weak results found so far may not be surprising. The results of experimental studies on conversational task performance are likely to be very sensitive to the specific design of the video-conferencing system and to the specific task tested. Video-conferencing systems differ a great deal with respect to video quality (size, resolution), the audio or video lag, the number of participants simultaneously visible and the configuration of cameras and monitors. Each of these aspects may influence specific aspects of the conversational process. Opposite effects may even have canceled each other.

## **1.2 The aim of this study**

The aim of this study was to isolate the effect of shared video spaces (including selective gaze) on conversational interaction and task outcome as compared to non-isotropic systems as well as face-to-face situations. For this purpose two mediated conditions were used that differed with respect to the configuration of monitors and cameras (isotropic/non-isotropic), but not with respect to other properties such as audio and video quality, transmission delay and console design (see Figure 1).

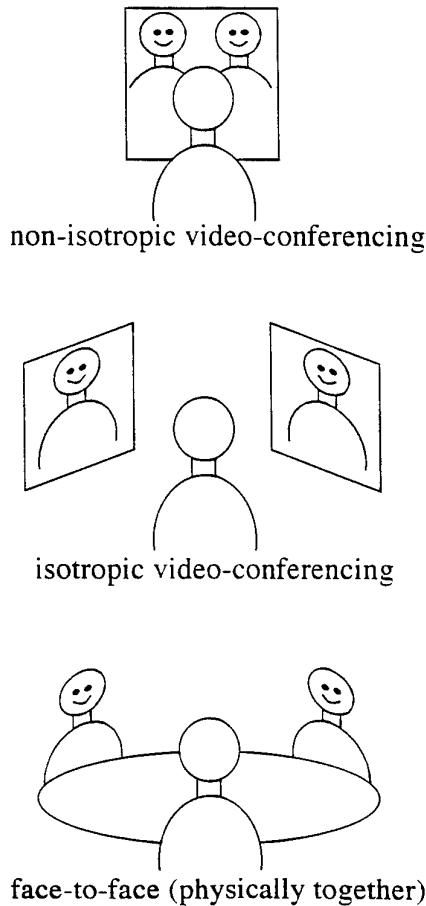


Fig. 1 A sketch of three conferencing conditions. Top: non-isotropic video conferencing. Each participant communicates through a single camera and a single monitor with colleagues. As a result everyone looks at everyone. Middle: isotropic video-conferencing. Participants communicate through a double camera and double monitor system. Participants are now virtually placed in a triangular configuration enabling selective gaze because of the spatially consistent viewing directions. Bottom: face-to-face condition. Participants share the same physical room and see each other directly (not through video connections).

To reveal possible differences in task outcome and conversational interaction between conferencing conditions we have tested a variety of discussion tasks. The communication of information was measured in a murder-solving task called "The Case of the Fallen Businessman". Dominance and persuasive force were revealed using a prioritization game of survival items called "Lost at the moon", featuring a dominant actor. Further, we quantified emotional behavior and the trade-off between individual and group benefits in a "prisoner's dilemma"-like management game. This collection of tasks addressed both collaborative and competitive behavior.

## 2 METHOD

### 2.1 Communication systems

To enable groups of three persons to perform tasks under video-conferencing conditions, three identical (tele)workplaces have been designed and built. The number of three participants has been chosen since this is the minimal number of people for which selective gaze may become important (when two persons communicate it is always clear which person is addressed). The workplaces allow for two modes of use, isotropic (selective gaze) and non-isotropic communication (no selective gaze). The non-isotropic workplaces consist of a single-camera, single-monitor setup per participant, resembling traditional videoconferencing setups. For the isotropic workplaces we used a multiple-camera and multiple monitor setup per participant which allowed to selectively look at another participant (selective gaze). Otherwise, the two mediated conditions were similar with respect to the monitors and cameras used and with respect to the audio quality. For the face-to-face condition (physically together around a table), no instrumentation was required. Details can be found in the next sections.

#### 2.1.1 Face-to-face condition (FF)

The face-to-face situation is the non-mediated situation in which people physically meet in the same room to communicate. During our face-to-face (FF) condition, three participants were placed in a quiet room at the same table. This condition supports the richest form of communication in which all aspects of verbal as well as non-verbal communication can be transmitted. The experiment leader was visibly seated at a table in the corner of the room.

#### 2.1.2 Non-Isotropic tele-COMmunication System (NICOS)

In contrast to the face-to-face situation, the NICOS condition is a mediated condition in which sound and light are carried by an electronic connection, sensed by microphones and cameras and displayed by speakers and monitors. Persons were physically separated and sat in different rooms (called cubicles). In these cubicles a work desk was placed consisting of a table and a cabinet used for housing a monitor, a load-speaker and a camera. Figure 2 shows the configuration.

NICOS is a picture-in-picture tele-conferencing unit in which participants observe each other on a single monitor per person which is divided in quadrants. Three quadrants were used to present the image of all other participants (top-left and top-right), including one's own image (bottom-left). The fourth quadrant was black. The images and audio of the participants was recorded by a single camera per person with an integrated microphone, placed above the monitor. The cameras zoomed in on the head and shoulders of the participants. All signals were sent to a Quad-unit which combined the pictures in quadrants. Audio signals were combined and distributed over the loudspeakers of the monitor.

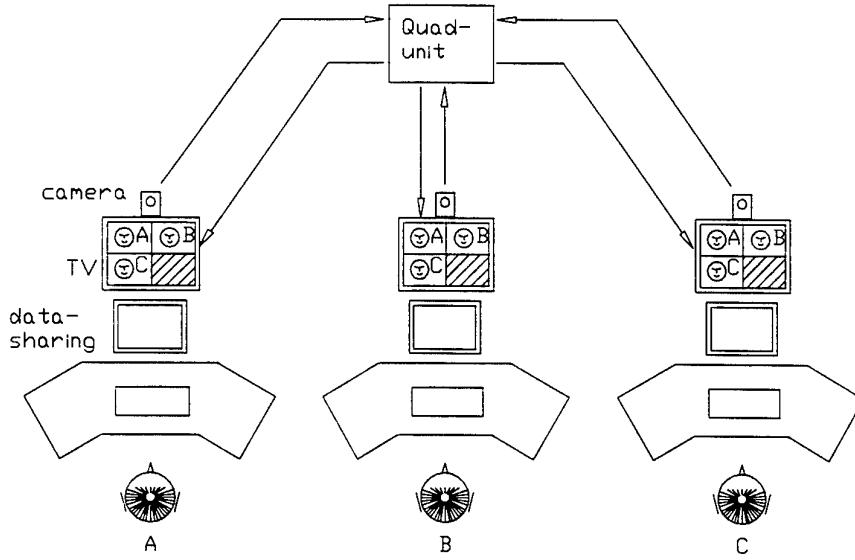


Fig. 2 Non-Isotropic video Conferencing System (NICOS). The set-up consists of a single camera and a single monitor per person. As a result everyone looks at everyone. Selective gaze is not possible.

Because a single camera and a single monitor were used for each individual NICOS system, selective gaze was not possible. Hence, participants were not seen in spatially consistent directions. Hence, the system is called non-isotropic.

#### 2.1.3 Isotropic tele-COMmunication System (ICOS)

ICOS is a tele-conferencing system alternative to NICOS because ICOS offers selective gaze. ICOS consists of an individual configuration with two cameras and two monitors per person. Figure 3 shows the configuration. As in NICOS, the participants were physically separated in different rooms, the cubicles. Video and audio signals of the two other participants were presented full-size on two separate monitors with integrated loudspeakers. People could not see their own picture.

As can be derived from Figure 3, the persons who participated in this three-point tele-conferencing were virtually placed in a triangular configuration. As a result the set-up approached the face-to-face situation, except that the direct view of a participant in a particular direction was replaced by an audio-video presentation in the same direction. The size of the video images presented was such that participants were virtually placed at distances of two meters relative to each other. This also allowed for displaying most of the upper-body of another participant. Consequently, not only facial expressions were visible, but also postures and arm or hand movements.

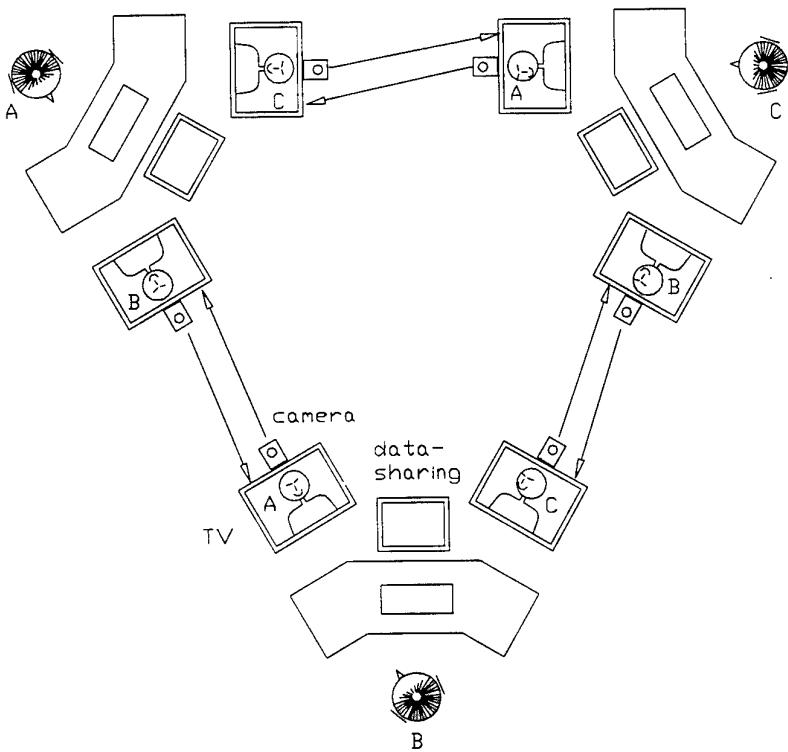


Fig. 3 Isotropic video Conferencing System (ICOS). The set-up consists of two cameras and two monitors per person. The camera and monitor configuration is such that participants virtually sit at the three corners of a triangle. This isotropic system enables selective gaze.

## 2.2 Apparatus

The workplaces for ICOS and NICOS were specially designed for these telework-experiments. ICOS and NICOS are equipped with the following apparatus:

### *TV sets*

Sony Trinitron Color TV, model no. KV-X2101D (diagonal: 51 cm) were used with a vertical resolution of approximately 500 visible lines. In ICOS, two TV sets were applied. Together with the user of the workplace, both TV sets were placed in a triangle. The distance between the user and the TV set was 1.25 m. In NICOS, one TV set was applied, positioned right in front of the operator (also at a distance of 1.25 m).

### *Cameras*

Sony Handycam Video 8 camera recorders, model no. CCD-TR330E, were used. These cameras were placed above the TVs. This position reduced the horizontal viewing angle to zero, the vertical viewing angle was reduced as much as possible.

### *Video-routing*

Video signals were split and routed using the Panasonic Quad Unit, model WJ-420/G. This Quad unit was applied in NICOS to combine pictures of all participants on a single screen.

### *Data-sharing*

Silicon Graphics Indy (R4600, Unix version 5.3) which consisted of a computer, monitor (21 inch), keyboard and mouse. These Indys were used to run InPerson 2.0, a data-sharing program of Silicon Graphics.

### *Consoles*

Three consoles were built to facilitate ICOS and NICOS. These consoles were designed to be compatible with the anthropometric dimensions of the Dutch population. Small as well as tall members of this population could use the consoles in the appropriate working posture. Based on the above the height of the working desk was 750 mm above the floor. The seat height of the chairs could be adjusted between 390 and 560 mm.

Figure 4 shows the design of the console. For ICOS it was possible to position two TVs. These TVs were placed in a triangle with the operator behind the console to create an isotropic communication space. The height of the TVs was in conformity with the height the operator's head. In the case of NICOS, one TV was removed and the remaining TV was placed in front of the operator. This TV showed a combined pictures of the three participants.

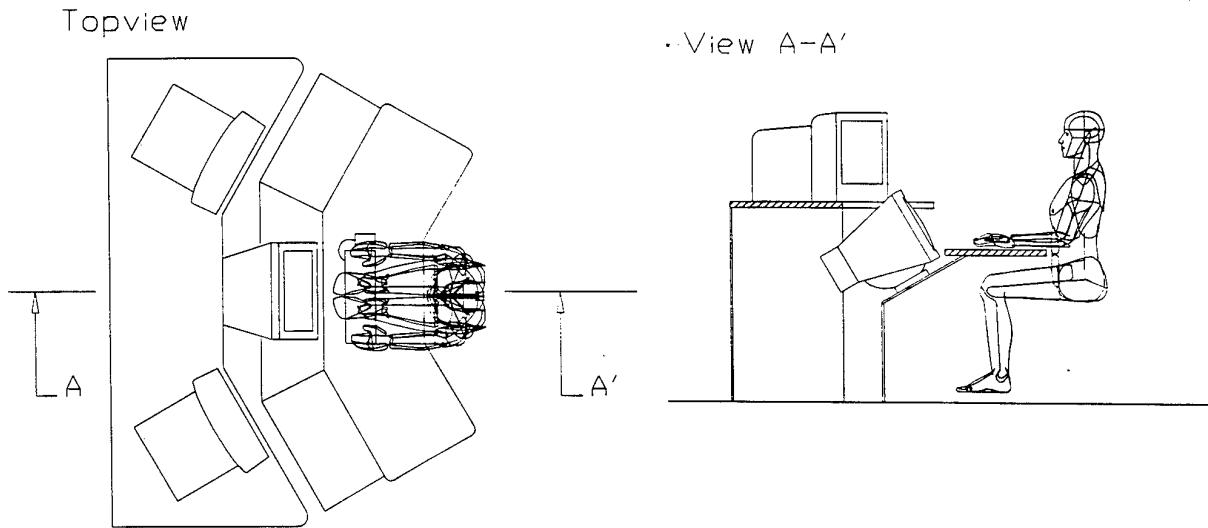


Fig. 4 Console design. This figure shows a cross section of the console.

The Indy-system was placed in front of the operator, built in the console. The operator had to look down to observe the Indy-monitor. For the other participants, it could always be seen whether a person was looking at the TV or looking down at the monitor of the Indy. The Indy-system did not cause visual obstruction when a participant had a look at the TV.

### 2.3 Tasks

Three tasks were applied. These tasks had to be carried out in the FF, NICOS and ICOS conditions.

The tasks were selected based on the diversity of measurements needed for investigating a wide range of effects on the communication process in different conditions. The tasks are described in the following sections.

#### 2.3.1 IG Game

##### *Aim of the IG-task*

The IG task is a “management” game in which collaboration is the optimal strategy to get the best average individual results (and thus the best group results). However, the rewards that are built in are such that participants are tempted to go for individual benefits (conflicting behavior). However, doing so they reduce the benefits of the group. Such dilemma is also known as the “prisoner’s dilemma”.

We have selected the IG-task to investigate possible differences in co-operation under different communication conditions. Which condition incites to competitive relations and which condition supports co-operation between the participants?

##### *Description*

In the “prisoner’s dilemma”-like IG game each of the three participants in the group could contribute an “I” or “G” card to a set of three cards each round. The value of an “I” or “G” card in a set depended on the amount of “I”-cards in the set. “I” cards are associated with “I”ndividual benefits, “G”-cards with “G”roup benefits. The total group score (the sum of individual scores) was highest (three points) when three “G” cards were contributed, each individual card valued 1 point. When only “I” cards were contributed the group score was minus three points (minus one point each). All other sets of cards had a zero-value group-result because the individually assigned positive values to “I” cards canceled the negative values of the “G” cards (see Table I).

Table I Score scheme for the IG task.

set			value			group score
G	G	G	1	1	1	3
G	G	I	-1	-1	2	0
G	I	I	-2	1	1	0
I	I	I	-1	-1	-1	-3

In between rounds the participants were allowed to discuss their individual or coordinated strategies with each other.

#### *Procedure*

The IG-game consisted of 20 rounds. Each participant started with an amount of Dfl. 10. =. For each point, the participant earned Dfl. 0.25. So, at the end of the game the amount of money could be increased to Dfl. 20. =, or decreased to zero. Participants were instructed to optimize their individual scores. After each round the sets were collected by the experiment leader. In case of ICOS or NICOS, the participants made their choice making use of an "I/G"-switch and the sets were presented on the data-sharing system after each round. During the face-to-face condition, participants wrote down their choice on a piece of paper which was handed over to the experiment leader. At each round the set of three choices was presented by the experiment leader on a whiteboard. Thus, the participants did not know at any time which choice was made by the other participants. Only the set of choices was presented.

#### *Dependent variables*

The dependent variables during the IG-game were the individual score, the variance in individual score, subjective ratings of mood states (POMS; Wald & Mellenbergh, 1990) and answers to a questionnaire.

The *individual score* was simply defined as the sum of points over 20 rounds which could theoretically vary between -40 (20 rounds of G,I,I-sets) and +40 (20 rounds of I,G,G-sets) when the same participant always made a choice different from the others. For details see Table I. When the choice of a participant "i" during round "n" is denoted as  $C_{i,n}$ , the individual score is:

$$S_i = \sum_n C_{i,n}$$

We also calculated the *variance*  $VAR(S_i)$  in individual scores within a group of three participants performing the IG task. The variance of individual scores as given in the result section for a particular condition is the variance averaged across the ten groups within that condition.

*Mood states* were measured before and after carrying out the IG task using a POMS (Profile Of Mood States) test. The POMS test scores the subjective ratings of mood states in five categories: Depression, Anger, Fatigue, Vigor and Tension.

A *Questionnaire* was filled in by the participants after the task had been carried out. This questionnaire consisted of several questions relating to group behavior, psychological distance, verbal communication, non-verbal communication, the system (face-to-face, isotropic or non-isotropic video conferencing) and emotions. Subjective ratings were asked on a five-point scale. The full list of questions is given in the Appendix (in Dutch). Questions that were irrelevant for a specific condition or task were left out in that case.

### 2.3.2 Lost At the Moon

#### *Aim of the Lost At The Moon task*

The Lost At The Moon task is group survival/ problem solving game in which participants have group discussions about a common strategy to survive at the moon. This task was selected for investigating the effects of the different communication conditions on persuasive force and on the quality of group solutions.

#### *Description*

The participants had to think of themselves as crew members of a spaceship which was originally scheduled to rendezvous with a mother ship on the lighted surface of the moon. Due to mechanical difficulties the spaceship had been forced to crash land at an unknown distance from the mother ship. It was further indicated that with the exception of 15 items all equipment was damaged during the crash landing. The available equipment had to be evaluated with respect to its importance for ensuring survival during the crew's cross-country trek to reach the mother ship.

Participants were asked to rank in order the 15 items for survival in terms of their relative value and utility for survival. An expert solution was known (Hall & Watson, 1970; see Table II) serving as a base line for the quality of the solutions of participants before and after a group discussion.

Lost At The Moon was carried out in teams of three participants. To control processes such as dominance and persuasive force one of the participants was an actor who played a dominant participant. This actor promoted a seriously wrong solution inducing strong equivocality (conflicting opinions). The fact that an actor took part in the experiment was not known to the other participants.

Table II Expert solution as given by the Crew Equipment Research Section of the NASA Manned Spacecraft Center at Houston, Texas (Hall & Watson, 1970).

Rank order	Item	Explanation
15	Box of matches	Useless since there is no oxygen on the moon
4	Food concentrates	Satisfies basic energy requirements
6	50 feet of nylon rope	Useful in scaling cliffs, tying injured together, etc.
8	Parachute silk	Protection from sun's rays
13	Portable heating unit	Only useful if on the dark side of the moon
11	Two .45 caliber pistols	Possible source of self-propulsion
12	1 case dehydrated pet milk	Duplicates food concentrate in bulkier form
1	2 hundred-pound tanks of oxygen	Absolute necessity for life support
3	Stellar map (of the moon's constellation)	Most important means of determining position and directions
9	Life raft	CO <sub>2</sub> bottle possible propulsion device
14	Magnetic compass	Virtually useless since magnetic field on the moon isn't polarized
2	5 gallons of water	Absolute necessity to sustain life
10	Signal flares	Possible distress signal once close enough to mother ship to be seen
7	First aid kit containing injection needles	Injection needles fitted to suit aperture quite useful
5	Solar-powered FM receiver-transmitter	Only useful if line-of-sight transmission is possible with limited transmission range

### *Procedure*

At the start of the Lost at the Moon task, participants were separated and had to rank the 15 items in order of their personal preference. This first individual solution was followed by a group discussion (approximately 30 minutes) in which the three participants had to generate a group solution. During the discussion participants were entirely free to exchange arguments and preferences. The predefined initial ranking of the actor (see Table III) which he defended during the group discussion was the same for all trials and conditions. Also the arguments put forward by the actor were the same for all conditions.

After the group solution was determined participants were separated and asked to write down their (second) individual solution, possibly influenced by the group discussion.

Table III The actor's predefined prioritization of the item list.

Rank order	Item	Explanation
3	Box of matches	Needed to observe the compass on the dark side of the moon
14	Food concentrates	Unable to eat through helmet
13	50 feet of nylon rope	On the moon everybody is weightless
12	Parachute silk	Too thin to carry stuff, too thin to keep the astronauts warm
4	Portable heating unit	Can be connected to the suits on the cold and dark side of the moon
6	Two .45 caliber pistols	Possible sound-signals for rescue
5	1 case dehydrated pet milk	Contains all possible food supplements
7	2 hundred-pound tanks of oxygen	There is enough oxygen in the suits
8	Stellar map (of the moon's constellation)	Stellar map only contains information of the light side of the moon.
15	Life raft	There's no water on the moon
2	Magnetic compass	Useful to reach mother ship
9	5 gallons of water	It's better to take milk instead of water since milk contains more food supplements
1	Signal flares	The most important thing is to be localized by the mother ship.
11	First aid kit containing injection needles	Useless
10	Solar-powered FM receiver-transmitter	Does not work at the dark side of the moon

#### *Dependent variables*

The Lost At The Moon task was carried out under the three communication conditions and the following dependent variables were measured:

- quality of pre-solution: the quality of the individual solution *before* the group discussion;
- quality of group solution: the quality of the group solutions after discussion;
- quality of post-solution: the quality of the individual solutions after the group discussion;
- interactional behavior: the number of handovers of the floor, number and durations of overlaps of speech during discussions. The measurements of these variables were recorded by the experiment leader, assisted by software.
- personality: The "Nederlandse Persoonlijkheid Vragenlijst" (Netherlands Personality Questionnaire, Luteijn et al., 1985) was used to measure the personality of participants.
- Questionnaire: see § 2.3.1

The quality (Q) of a solution (prioritized list) ( $L_i$ ) is defined as Spearman's coefficient  $r_s$  of the rank correlation with the expert solution called E (see Table II):

$$Q = r_s = 1 - \frac{6 \sum_{i=1}^n (L_i - E_i)^2}{n(n^2 - 1)}$$

where “ $L_i$ “ denotes the ranking of item “ $i$ ” and “ $n$ ” is the length of the item list. Spearman’s correlation coefficient can vary between -1 and 1.

Using this quality measure we have calculated the quality of the actor’s predefined non-optimal item list. This quality  $r_s = -0.56$  can be considered the bottom-line of the negative influence of the actor on the group solution.

### 2.3.3 The Case of the Fallen Businessman

#### *The aim of The Case of the Fallen Businessman*

The Case of the Fallen Businessman is a murder solving task. This task was selected for measuring the influence of the three communication conditions on the distribution of unshared data during a cooperative task.

#### *Description*

The Case of the Fallen Businessman is based on the experiments of Stasser, Stewart and Wittenbaum (1995). Participants have to read a series of interviews from a homicide investigation. These interviews are contained in a booklet that also includes other material such as maps of the city and the site of crime, a note ostensibly written by one of the suspects, and a newspaper article summarizing background information. The participants task is to choose which of the three male suspects (Eddie, Billy, or Mickey) was most likely to be guilty. The interview contains 24 clues that incriminate or exonerate particular suspects. Specifically, there were six incriminating clues for each suspect, but there were also three clues that exonerate suspect Billy and three clues that exonerate suspect Mickey. The total set of 24 clues is designed such that suspects Billy and Mickey can be ruled out as viable suspects. Moreover, the full set of clues supports the conclusion that suspect Eddie had a motive as well as an opportunity to commit the crime and had attempted to frame suspect Billy. The 24 clues are distributed over the participants such that 15 clues were shared and 9 clues were unshared. Of the 15 shared clues, three incriminate Eddie, 6 incriminate Billy and 6 incriminate Mickey. The 9 remaining clues are critical for identifying suspect Eddie as the guilty party. These critical clues are unshared and distributed: one participant receives three clues that incriminate suspect Eddie, one participant receives three clues that exonerate suspect Mickey, and one participant receives three clues that exonerate suspect Billy.

The Case of the Fallen Businessman has been set up such that is difficult to analyze the case even when all information is available.

### *Procedure*

First, participants individually read and reviewed the booklets in about 20 minutes. The individual booklets contained shared information (available to each participant) and unshared information (available only to a single participant). However, none of the participants knew which information was shared and which information was unshared. The participants then indicated (judged) which suspect they thought was most likely to be guilty on an individual private questionnaire.

After this individual judgement, a discussion took place in which the participants discussed the case together. All communication conditions were tested for this task. After a maximum of 45 minutes, the participants had to decide as a group which suspect was most likely to be guilty.

### *Dependent variables*

The following dependent variables were measured for the “The Case of the Fallen Businessman” task:

- Individual judgements: judgements before the group discussion (Eddie, Billy, or Mickey);
- Group judgements: judgements after the group discussion (Eddie, Billy, or Mickey);
- Information sharing: the number of unshared clues communicated during the group discussion (an unshared clue that was mentioned one or more times during the discussion contributed one point to “the amount of information sharing”, clues that weren’t mentioned contributed zero points);
- Completion time: the duration of the group decision;
- Questionnaire: see § 2.3.1

## **2.4 Experimental design**

### *Design*

To eliminate the undesirable transfer of knowledge about a particular task from one condition to another, we have chosen for a design in which each participant carried out each task only once. As a consequence, the design allowed to compare tasks within participants, but conferencing conditions (isotropic versus non-isotropic) between participants only.

Table IV shows the sequence of tasks for nine participants ( $A_n \dots I_n$ ) tested on day  $n$ . Each day only a single mediated condition was tested. On days  $n = 1 \dots 5$  the mediated condition tested was non-isotropic video-conferencing. On days  $n = 6 \dots 10$  the isotropic video-conferencing was tested. The face-to-face conditions were tested on all days ( $n = 1 \dots 10$ ).

Because the Lost at the Moon task was carried out with only two participants and one actor, each day three participants were excluded from the Lost at the Moon tasks.

Table IV Sequence of tasks and conditions for participants A<sub>n</sub> ... I<sub>n</sub> on day "n".

Participant	Lost at the Moon		IG management game		Case of the Fallen Businessman	
	Mediated	Face-Face	Mediated	Face-Face	Mediated	Face-Face
A <sub>n</sub>		T <sub>3</sub>		T <sub>2</sub>	T <sub>1</sub>	
B <sub>n</sub>			T <sub>2</sub>		T <sub>1</sub>	
C <sub>n</sub>		T <sub>3</sub>		T <sub>2</sub>	T <sub>1</sub>	
D <sub>n</sub>	T <sub>3</sub>		T <sub>1</sub>		T <sub>2</sub>	
E <sub>n</sub>	T <sub>3</sub>			T <sub>1</sub>	T <sub>2</sub>	
F <sub>n</sub>			T <sub>1</sub>		T <sub>2</sub>	
G <sub>n</sub>	T <sub>2</sub>		T <sub>3</sub>			T <sub>1</sub>
H <sub>n</sub>			T <sub>2</sub>			T <sub>1</sub>
I <sub>n</sub>	T <sub>2</sub>		T <sub>3</sub>			T <sub>1</sub>

T<sub>i</sub> denotes that this task was the "i"th task carried out by this participant.

Table V Time schedule for testing participants.

Time	Start/instruction	Case of the fallen businessman		IG game		Lost at the moon		Pause	End
		face-to-face	NICOS/-ICOS	face-to-face	NICOS/-ICOS	face-to-face	NICOS/-ICOS		
9:00-9:30	A,B,C								
9:30-10:35			A,B,C						
10:35-11:00	D,E,F							A,B,C	
11:00-11:35				A,E,C	B,D,F				
11:40-12:45			D,E,F			A,C,act			B
12:50-13:30	G,H,I							D,E	A,C,F
13:30-14:35		G,H,I					E,D,act		
14:40-15:45							I,G,act	H	E,D
15:50-16:20				I,G,H					

A ... I denote the participants A ... I.

After ten days the number of participants tested was distributed as follows across tasks and conditions: 20 participants per condition tested for the Lost at the Moon task; 30 participants per condition tested for the IG tasks and 30 participants per condition for the Case of the Fallen Businessman task.

Table V shows the time-schedule during the experiments. Each day, nine participants (A ... I) arrived in groups of three persons. To avoid unnecessary delay, each group of three participants was extended with a "spare" participant who could replace a participant that did not show up.

#### *Instructions*

The participants started with an instruction of the experiment leader. During this instruction the participants were informed about different tasks and the conditions in which these tasks had to be carried out. As a part of the instruction, the working principles of ICOS or NICOS (depending on which day the experiment took place) were explained. The actor pretended to be a normal participant, joined the instructions, filled in the questionnaires, etc.

#### *Data collection*

During the experiments, all dependent variables were measured as specified in the task descriptions. The Netherlands Personality Questionnaire was filled out during a pause or introduction of the participants before carrying out any task. Video recordings were made of all tasks carried out in the mediated conditions and the first five days of the face-to-face situations. The Profile of Mood States questionnaire was filled out by the participants before and after carrying out the IG task.

### **2.5 Analysis**

Each task was carried out only once for a single communication condition. Thus, we can compare results only between subjects, not within subjects. For each dependent variable of each task, we carried out an ANOVA analysis with a single independent variable (the communication condition). This variable (face-to-face, mediated isotropic or mediated non-isotropic) had two degrees of freedom. We have calculated the F-values for the main effect of communication condition. The number of degrees of freedom for the ANOVA analysis depended on the number of participants or groups involved in the analysis. Moreover, the degrees of freedom varied because values that differed more than two standard deviations from the average for a particular condition were considered outliers and were left out of the analysis. Further, we carried out Tukey significance tests for revealing possible significance of differences between conditions. Because of the exploratory nature of this research we will consider effects significant at 90% confidence levels.

## 2.6 Participants

The group of participants consisted of 80 students (40 male, 40 female). None of the participants were familiar with the tasks. Participants that had to carry out tasks together did not know each other. Participants were paid for their participation. Depending on the outcome of the “IG”-game, participants earned a bonus.

## 3 RESULTS

### 3.1 Results IG Game

We recall that in the “prisoner’s dilemma”-like IG game each of the three participants in the group could contribute an “I” or “G” card to a set of three cards each round. The value of an “I” or “G” card in a set depended on the amount of “I”-cards in the set.

We have collected the following measures of task performance: individual scores and the variance of individual scores.

#### 3.1.1 Individual scores

- *Average individual scores*

The individual score of a participant is defined as his sum of points over 20 rounds. Table VI shows the average individual scores across participants for each condition. The results of a Tukey significance test between conditions are added. Participants show significantly higher individual scores ( $p < 0.05$ ) under video-conferencing conditions than under face-to-face conditions. The same holds for the group result which is the sum of individual scores within a group. This must be the result of more focus on group benefit under mediated conditions. No significant differences were found between isotropic and non-isotropic video-conditions.

Table VI Average individual scores of the IG task.

ANOVA $F(2,84) = 5.73, p = 0.005$ (3 participants excluded)	average individual scores	Tukey significance test		
		face-to-face	isotropic	non-isotropic
face-to-face	1.25	-	$p = 0.02$	$p = 0.01$
isotropic	8.20	$p = 0.02$	-	$p = 0.90$
non-isotropic	9.31	$p = 0.01$	$p = 0.90$	-

The average individual scores are also presented graphically in Figure 5.

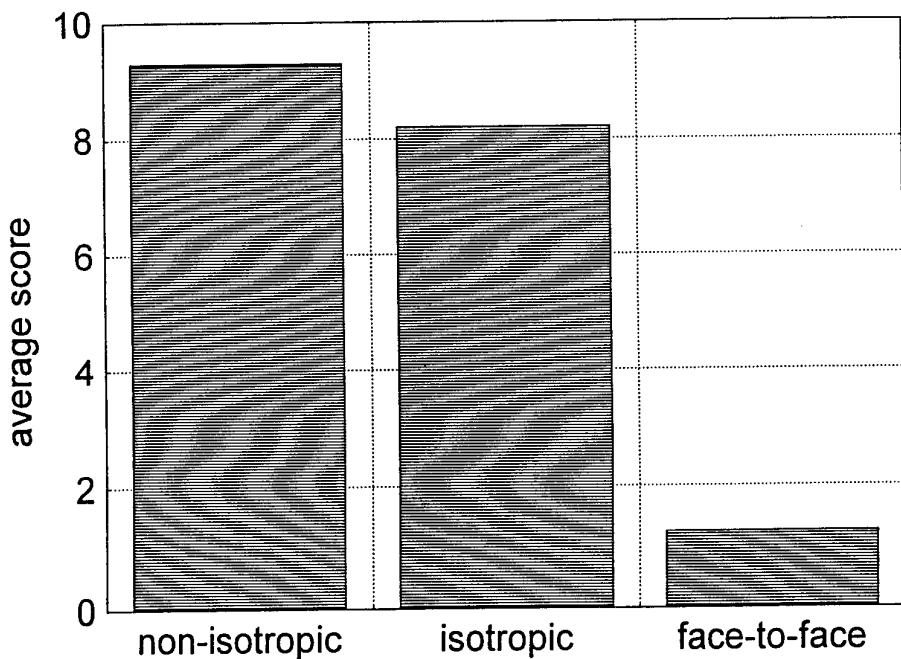


Fig. 5 Average individual score for the IG task.

- *Variance in individual scores*

With the variance of individual scores we mean the variance in individual points within a group of three participants that carried out the IG task. The presented variance for a condition is the variance averaged across ten groups that were tested per condition.

From Table VII we observe that participants show more variance under face-to-face conditions than under video-conferencing conditions (though only the difference between face-to-face and non-isotropic conditions is significant,  $p < 0.10$ ). This finding of more homogeneous choices under video-conferencing conditions indicates more focus on group benefit which is consistent with the higher average of individual scores.

Table VII Variance in individual scores of the IG task.

ANOVA $F(2,25)=2.49, p=0.10$ (2 participants excluded)	variance in individual scores	Tukey significance test		
		face-to-face	isotropic	non-isotropic
face-to-face	46.1	-	$p=0.32$	$p=0.09$
isotropic	27.2	$p=0.32$	-	$p=0.73$
non-isotropic	17.4	$p=0.09$	$p=0.73$	-

### 3.1.2 Profile of Mood States (POMS)

The tests called Profile of Mood States (POMS) scores the subjective ratings of mood states in five categories: Depression, Anger, Fatigue, Vigor and Tension. We have found no significant differences in ratings between conditions for the categories Depression, Anger, Fatigue or Vigor. However, in the category Tension the different conditions gave significantly different results ( $p < 0.10$ , see Table VIII).

Table VIII Results of the Profile of Mood Scale.

ANOVA $F(2,87)=2.78, p=0.07$	POMS score: Tension	Tukey significance test		
		face-to-face	isotropic	non-isotropic
face-to-face	7.87	-	$p=0.91$	$p=0.07$
isotropic	7.63	$p=0.91$	-	$p=0.18$
non-isotropic	6.63	$p=0.07$	$p=0.18$	-

Tension is significantly lower under non-isotropic conditions than under face-to-face conditions (less gambling, more group-benefit). No significant differences were found between mediated conditions.

### 3.1.3 Questionnaire

The IG task is a task that may lead to competitive behavior with a high “poker” level. Therefore we have selected a few questions that might reveal something about the feelings and behavior of participants during the game. The questions are:

- Were you afraid for a confrontation with the other participants?
- Did you have the feeling of being able to fool other participants?
- Did you have the feeling that other participants knew what you were up to?

The results can be summarized easily: no significant differences between conditions were found.

### 3.1.4 Discussion IG game

Generally, researchers have hypothesized that mediated communication conditions yield a *larger* psychological distance than face-to-face conditions. Such a larger psychological distance may result in more confronting or competitive behavior. As a result there will be more focus on individual benefits which has a negative effect on the group score.

Because the term psychological distance is more a concept than a clear definition, direct objective measures of psychological distance do not exist. However, the influence of this underlying mechanism can be derived from quantifiable measures such as tension (competitive behavior) and group score (focus on group benefit).

Interestingly, our findings show the opposite of the general hypothesis that mediated communication leads to a lower group result. In contrast, we find that mediated conditions yield higher group results (see the average individual score in Table VI) than face-to-face conditions because of more cooperative behavior. More cooperative behavior during the IG task is expected to go along with more homogeneous choices (less variance) which was indeed observed (Table VII). Furthermore, cooperative behavior is expected to involve less tension than competitive behavior which was also observed (Table VIII).

By reasoning back-wards, our mutually consistent findings suggest that the experienced psychological distance under mediated conditions is even *smaller* than under face-to-face conditions.

## 3.2 Results Lost at the Moon

### 3.2.1 Quality of solutions

The quality of a solution is defined as the Spearman's coefficient  $r_s$  of the rank correlation with the expert solution (see § 2.3.2). We have calculated the quality of individual pre- and post-solutions (*before* and *after* the group discussions) and the quality of the group solutions.

- *Quality of individual pre-solutions*

First we have calculated the average quality  $Q_1$  of individual pre-solutions across participants per communication condition. There are no a priori reasons to expect a difference between conditions in the average quality of individual pre-solutions because no communication between participants had taken place at that time. The average quality of the pre-solution serves as a base-line to discuss the changes in quality induced by the group discussion. The average values of quality of the individual pre-solutions, their variance and Tukey significance test results are presented in Table IX (see also Figure 6).

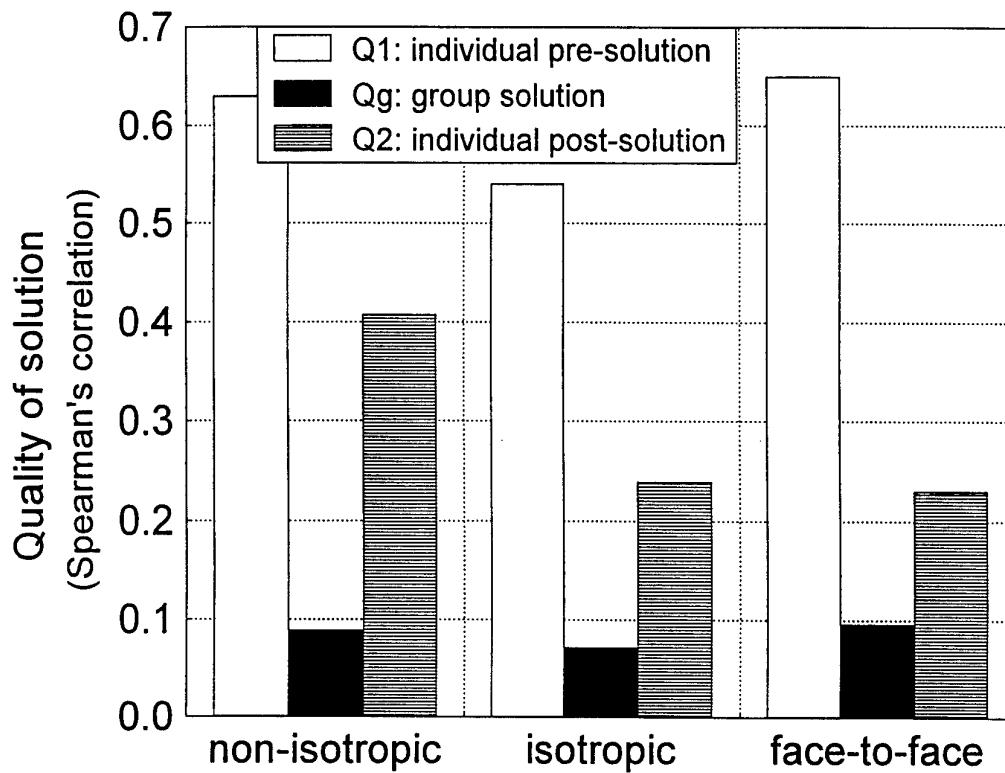


Fig. 6 Average quality of individual pre- and post-solutions, and the group solutions.

Table IX Quality of pre-solutions,  $Q_1$ .

ANOVA $F(2,52)=5.06, p=0.01$ (3 participants excluded)	$Q_1$	Tukey significance test		
		face-to-face	isotropic	non-isotropic
face-to-face	0.65	-	$p=0.01$	$p=0.87$
isotropic	0.54	$p=0.01$	-	$p=0.05$
non-isotropic	0.63	$p=0.87$	$p=0.05$	-

Indeed face-to-face and non-isotropic conditions show no significant differences. However, the isotropic video-condition differs slightly but significantly ( $p < 0.05$ ) from the other conditions. We have no reasonable explanation for this unexpected deviation other than bad luck.

- *Quality of group solutions after the group discussion*

Individual solutions and arguments were discussed during the group discussion leading to a group solution of which the quality was calculated across the ten groups per condition. The average values of quality of group solutions, their variance and Tukey significance test results are presented in Table X (see also Figure 6).

Table X Quality of group solutions after the group discussion,  $Q_g$ .

ANOVA $F(2,24)=0.05$ , $p=0.95$ (2 groups excluded)	$Q_g$	Tukey significance test compared with:		
		face-to-face	isotropic	non-isotropic
face-to-face	0.10	-	$p=0.95$	$p=1.00$
isotropic	0.07	$p=0.95$	-	$p=0.98$
non-isotropic	0.09	$p=1.00$	$p=0.98$	-

The average quality of group solutions (0.09) was much lower than the initial individual solutions (0.61). This can be taken as a measure for the *dominance* of the actor, that is, the amount of negative influence the actor can have during the discussion on the solution of the group. The quality of group solutions does not differ significantly between conditions.

- *Quality of individual post-solutions*

To see if participants had really been convinced by the arguments of the actor that led to a decrease of the group solution, we measured the individual solutions again after the group solution was determined (the post-solution). The average quality of the individual post-solutions, their variance and Tukey significance test results are presented in Table XI (see also Figure 6).

Table XI Quality of individual post-solutions,  $Q_2$ .

ANOVA $F(2,54)=3.60$ , $p=0.03$ (1 participant excluded)	$Q_2$	Tukey significance test		
		face-to-face	isotropic	non-isotropic
face-to-face	0.23	-	$p=0.99$	$p=0.05$
isotropic	0.24	$p=0.99$	-	$p=0.07$
non-isotropic	0.41	$p=0.05$	$p=0.07$	-

The average quality of individual post-solutions under non-isotropic video-conditions differs significantly from the other conditions ( $p < 0.10$ ). In the non-isotropic condition participants appear least convinced of the arguments of the actor that led to a decrease of the group solution. Such recovery can be taken as a measure of belief in the arguments of the actor (*persuasive force*). It appears that the persuasive force is less strong under non-isotropic conditions than under isotropic conditions.

- *Difference between the quality of individual post- and pre-solutions*

It cannot be excluded that the significant difference of quality of the post-solution  $Q_2$  between non-isotropic and isotropic conditions was caused by the already significant lower quality of

pre-solution  $Q_1$  under isotropic conditions. Therefore, we have calculated the average values of  $(Q_2 - Q_1)$  across participants for each condition (see Table XII).

Table XII Difference between the quality of individual post- and pre-solutions.

ANOVA $F(2,51)=2.58, p=0.08$ (4 participants excluded)	$(Q_2 - Q_1)$	Tukey significance test		
		face-to-face	isotropic	non-isotropic
face-to-face	-0.40	-	$p=0.31$	$p=0.08$
isotropic	-0.28	$p=0.31$	-	$p=0.74$
non-isotropic	-0.22	$p=0.08$	$p=0.74$	-

The difference between the quality of individual post- and pre-solutions under non-isotropic video-conditions differs significantly ( $p < 0.10$ ) from the face-to-face condition, just as found for  $Q_2$ . The quality under non-isotropic conditions, however, is not significantly better. This means that the effect of a lower initial quality  $Q_1$  under isotropic conditions on  $Q_2$  cannot be excluded.

- *Difference between the quality of post- and group solutions*

The recovery from the quality-decreasing group discussion as measured by the individual post-solutions can also be measured directly by taking the difference between the quality of the individual post-solutions and the quality of the group solution.

Table XIII Difference between the quality of post- and group solutions.

ANOVA $F(2,50)=7.31, p=0.002$ (5 participants excluded)	$(Q_2 - Q_g)$	Tukey significance test		
		face-to-face	isotropic	non-isotropic
face-to-face	0.11	-	$p=0.54$	$p=0.002$
isotropic	0.17	$p=0.54$	-	$p=0.02$
non-isotropic	0.32	$p=0.002$	$p=0.02$	-

The difference between the quality of group and post-solutions under non-isotropic video-conditions differs significantly from the other conditions ( $p < 0.05$ ). This is consistent with the observed absolute values of  $Q_2$ .

- *Correlation between the change of  $Q_2$  relative to  $Q_1$  and the change of  $Q_2$  relative to  $Q_g$*

It is of interest to further scrutinize the data and to consider not only the differences between averages of different conditions but to also consider correlations between individual perform-

ances and group performances within conditions. For example, does the difference between the qualities of the two individual solutions  $Q_2 - Q_1$  correlate with the difference between the qualities of the group and the individual solution  $Q_g - Q_1$ . In other words, does sensitivity to dominance as measured by  $Q_g - Q_1$  have predictive power for persuasive force as measured by  $Q_2 - Q_1$  at an individual level? Therefore we have calculated the correlation levels for each communication condition (see Table XIV). We calculated the correlation of  $(Q_2 - Q_1)$  with  $(Q_g - Q_1)$  which is denoted as  $(Q_2 - Q_1) \otimes (Q_g - Q_1)$ .

Table XIV Correlation coefficients.

Condition	Correlation coefficient of $(Q_2 - Q_1) \otimes (Q_g - Q_1)$
face-to-face	$r = 0.73$
isotropic	$r = 0.85$
non-isotropic	$r = 0.37$

Correlation coefficients of  $(Q_2 - Q_1) \otimes (Q_g - Q_1)$  are significantly lower (two-sided significance test for the difference between correlation coefficients,  $n=20$ ) under non-isotropic conditions than under other conditions. This suggests that the actor's dominance resulting in a decrease of the quality of the group solution has considerably less impact on the individual post-solution under non-isotropic conditions. The arguments of the actor seem less convincing under non-isotropic video conditions. This is consistent with the observation that the average quality of individual post-solutions is less affected by the group discussion under non-isotropic conditions than under other conferencing conditions (see Table XI).

### 3.2.2 Interactional behavior

So far, we have reported on the quality of solutions (task outcome) resulting from the group discussions. Here we focus on the interactional process during group discussions in terms of interruption behavior. We have measured the following variables for each condition:

- Number of handovers of the floor: the number of times that a speaker gives the floor to another speaker.
- Number of overlaps: the number of times that participant started speaking though the previous speaker had not yet finished.
- Average duration of overlap (in seconds).

Table XV Quantification of interactional behavior.

variable	face-to-face	isotropic	non-isotropic
number of handovers	172	162	167
number of overlaps	6.4	15.6	7.5
duration overlaps (s)	2.7	3.3	3.7

None of the measures given in Table XV differed significantly between conferencing conditions. However, a systematic effect has been observed. Mediated conditions (isotropic as well as non-isotropic) differ systematically from the face-to-face condition: less frequent handovers of the floor, more frequent and longer overlaps. These differences all indicate that the timing of interruptions is more problematic under mediated conditions. The probability of finding that these differences consistently point in this direction, if no effects of conditions exist, would be  $2^{-6}$  or 1.6%.

### 3.2.3 Questionnaire

Some questions of the questionnaire are specifically interesting to discuss in relation to the Lost at The Moon task. Here we discuss some questions that may partially explain the differences in task-outcome found between conditions. Ratings for the Lost at the Moon task have been averaged across subjects.

*Was it clear who wanted a response from who (not ... very)?*

Generally, a question can be addressed to a specific participant by mentioning names, by pointing or by selective gaze. The appreciation of the conditions with respect to addressing questions was higher under isotropic conditions (4.69, averaged across face-to-face and mediated isotropic) than under non-isotropic conditions (3.28). Although the effect was not significant ( $p=0.15$ ) it suggests that isotropy facilitates addressing questions by means of pointing or selective gaze.

*Were you able to determine the viewing direction of other persons (never ... always)?*

As expected, the appreciation of being able to determine each others viewing direction under isotropic conditions (4.93 averaged across face-to-face and mediated isotropic) was significantly higher ( $p=0.02$ ) than for the non-isotropic condition (2.67).

*Have you had eye-contact with other participants (never ... regularly)?*

This question reveals the subjectively rated frequency of eye-contact during the group discussion. The average ratings are 4.2 for the face-to-face condition, 3.9 for the isotropic condition and 2.9 for the non-isotropic condition. The subjective rating of the frequency of eye-contact is significantly lower under the non-isotropic video condition than under the face-to-face condition. This may explain the observation of less belief in the arguments of the actor in the non-isotropic condition assuming that persuasive force is facilitated by eye-contact.

*Did you get angry at other participants (not ... very)?*

This rating shows the self-rated anger during group discussions. The average ratings of anger were 2.1 for the face-to-face conditions, 1.4 for the isotropic condition and 1.7 for the non-isotropic condition. Under the face-to-face condition participants scored significantly higher ( $p=0.07$ ) on anger than under isotropic video-conferencing conditions.

### 3.2.4 Discussion Lost at the Moon

We have found convincing evidence that non-isotropic and isotropic video-conferencing conditions score *differently* with respect to *persuasive force* (the actor's arguments are less convincing under non-isotropic conditions) but *similarly* with respect to *dominance*. Further, performance under isotropic conditions does not significantly differ from performance under face-to-face conditions.

The frequency of floor changes can be taken as a measure for involvement, interactivity and spontaneity. Further, the average duration of overlap is seen as a measure of the ease of regulating the conversation (Sellen, 1995). Hence, the results suggest that mediated conversation is less spontaneous, less interactive and less regulated.

These suggestions are contrary to observations by Sellen (1995). Sellen used objective measures to show that under the face-to-face condition people produce significantly more interruptions (overlaps) and fewer formal handovers of the floor than in any other mediated condition (audio-only and video-conferencing conditions).

The results of the questionnaire indicate that the isotropic mediated condition was appreciated more than the non-isotropic condition with respect to regulating the conversation with non-verbal behavior (eye-contact, selective gaze). At the same time, the persuasive force of the actor appears to be higher under the isotropic condition (see Table XI). It is likely that non-verbal behavior and persuasive force are correlated.

The fact that the self-rated anger was lower under the mediated conditions than under the face-to-face condition is not reflected in the results because, for example, the quality of solutions did not differ between the isotropic mediated condition and the face-to-face condition.

## 3.3 Results The Case of the Fallen Businessman

First, we have calculated the percentage of correct individual judgements (based on the booklets, before the group discussion) of who was "guilty". This percentage varied between 36% and 43% (across 30 participants per condition). A Kruskal-Wallis test (a non-parametric one-way analysis of variance) showed that the differences between conditions were not significant ( $p=0.95$ ). Second, we have calculated the percentage of correct group judgements (after the group discussions). This percentage varied between 40% and 60% (across 10 groups of three participants per condition). Again differences between conditions were not significant ( $p=0.60$ ), just as were the completion times of the group discussions.

### 3.3.1 Communicated unshared items

During the experiments we scored the frequency with which unshared items were communicated during the group discussion. When an unshared item was communicated one or more times it was labeled "1". When it was not mentioned it was labeled "0". Note that an item that was mentioned more than one time contributes only 1 point, identical to an item that was mentioned only once. In fact, we have scored the amount of non-redundant information that was communicated.

Table XVI Quantification of the communication of unshared items.

ANOVA $F(2,25)=3.15, p=0.06$	Communicated unshared items	Tukey significance test		
		face-to-face	isotropic	non-isotropic
	face-to-face	0.68	-	$p=0.06$
	isotropic	1.28	$p=0.06$	-
	non-isotropic	1.15	$p=0.18$	$p=0.86$

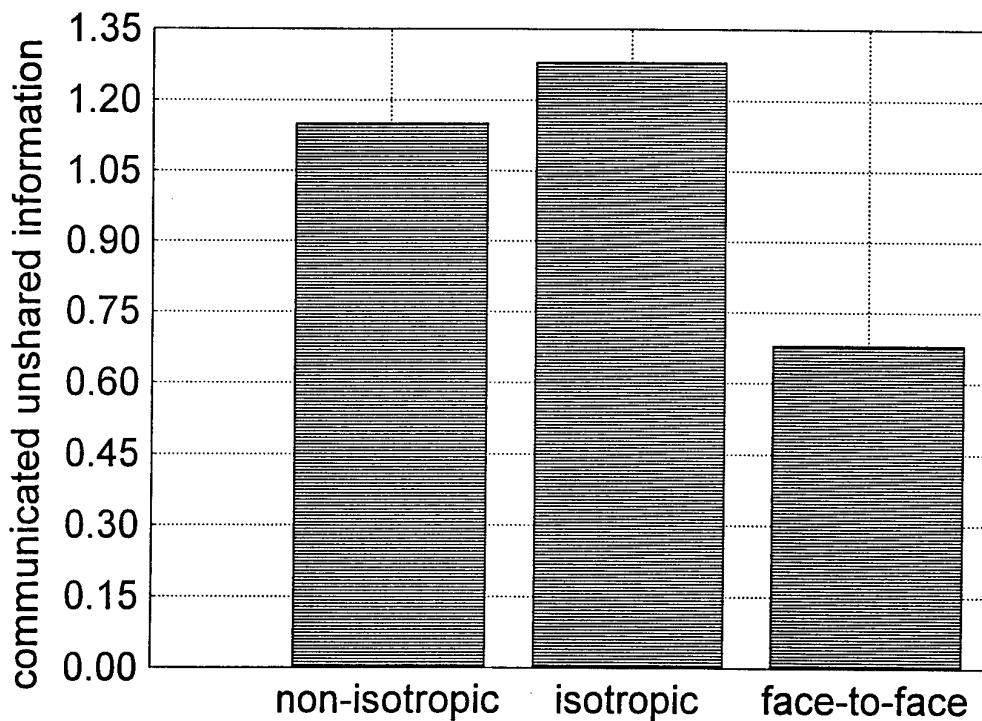


Fig. 7 Average amount of communicated unshared information.

From Table XVI and Figure 7 it is clear that under isotropic conferencing conditions participants communicate significantly more unshared information ( $p < 0.10$ ) than under face-to-face conditions (almost twice as much). A similar effect is observed for the non-isotropic conditions, but is not significant.

### 3.3.2 Questionnaire

The actual amount of information shared with other participants depends on the willingness to share the information (e.g., team spirit, psychological distance) and the ease of regulating the conversation (eye-contact, selective gaze, etc.). Both aspects may have been influenced by the properties of the communication medium used. Some questions of our questionnaire related to these issues resulted in significantly different ratings between conditions and will be discussed in more detail.

A question related to team spirit is: "Did you have the feeling of being part of a team?". This question was rated between 1 (when participants did not have such feelings at all) and 5 (when they had strong feelings like that). Table XVII shows the rating results averaged across the subjects that participated in "The Case of the Fallen Businessman" experiment.

Table XVII Subjective ratings of the feeling of being part of a team.

Did you have the feeling of being part of a team (1: not at all ... 5: very strong)?	rating	Tukey significance test		
		face-to-face	isotropic	non-isotropic
face-to-face	3.6	-	$p=0.01$	$p=0.00$
isotropic	4.2	$p=0.01$	-	$p=0.71$
non-isotropic	4.4	$p=0.00$	$p=0.71$	-

Obviously, participants had significantly ( $p < 0.05$ ) stronger feelings of being part of a team under mediated conditions than under the face-to-face condition. No significant differences were found between mediated conditions.

Another question related to team spirit was: "Have you experienced a distance between you and the other participants?". Table XVIII shows the ratings results for this question.

Table XVIII Subjective ratings of the experienced distance to other participants.

Have you experienced a distance between you and the other participants (1: not at all ... 5: very strong)?	rating	Tukey significance test		
		face-to-face	isotropic	non-isotropic
face-to-face	3.9	-	$p=0.00$	$p=0.00$
isotropic	2.0	$p=0.00$	-	$p=0.81$
non-isotropic	2.1	$p=0.00$	$p=0.81$	-

Again the mediated conditions yield significantly ( $p < 0.05$ ) different results than the face-to-face condition. Participants experienced less distance to other persons when performing the communication tasks under mediated conditions than under face-to-face conditions.

Sharing information may also depend on how well participants were able to communicate non-verbal information. For example, eye-contact and selective gaze may facilitate the regulation of the conversation. The rating results for the question "Have you had eye-contact with other participants?" (Table XIX) and "Were you able to determine the viewing direction of other persons?" (Table XX) show similar effects. Eye-contact and selective gaze were rated highest for the isotropic video condition, even higher than for the face-to-face condition. Lowest ratings were found for the non-isotropic video condition. The non-isotropic condition differed significantly from the isotropic video condition in both cases.

Table XIX Subjective ratings of eye-contact.

Have you had eye-contact with other participants (1:never ... 5:regularly)?	rating	Tukey significance test		
		face-to-face	isotropic	non-isotropic
face-to-face	3.7	-	$p=0.14$	$p=0.14$
isotropic	4.3	$p=0.14$	-	$p=0.00$
non-isotropic	3.1	$p=0.14$	$p=0.00$	-

Table XX Subjective ratings of selective gaze.

Were you able to determine the viewing direction of other persons (1:never ... 5:always)?	rating	Tukey significance test		
		face-to-face	isotropic	non-isotropic
face-to-face	3.9	-	$p=0.29$	$p=0.01$
isotropic	4.4	$p=0.29$	-	$p=0.00$
non-isotropic	3.0	$p=0.01$	$p=0.00$	-

### 3.3.3 Discussion The Case of the Fallen Businessman

The percentage of correct judgements did not differ significantly between conditions. This was expected since even the combined sets of shared and unshared clues did not provide enough information to reach a correct conclusion with a 100% probability. The Case of the Fallen Businessman has been set up such that it is difficult to analyze the case even when all information is available.

However, our results prove that participants communicate significantly more unshared information under mediated isotropic communication than under the face-to-face condition. Further, the data strongly suggest a similar increase of information sharing under the non-isotropic condition. All together we conclude that video conferencing stimulates the exchange

of (unshared) information. This finding is consistent with the findings that, under mediated conditions, participants felt more part of a team and experienced a *smaller* distance to other participants than under face-to-face conditions. Furthermore, at least under isotropic mediated conditions, the possibility of eye-contact and selective gaze may have facilitated the regulation of the conversation and therefore the sharing of information.

#### 4 GENERAL DISCUSSION

In our introduction we have hypothesized that task-outcomes under mediated conferencing conditions may be affected due to a non-optimal communication of non-verbal behavior. More specifically, we hypothesized that a shared isotropic video space in which participants see each other in spatially consistent directions (selective gaze) would facilitate the regulation of interactional conversation and decrease "social nearness" (Short, Williams & Christie, 1976) experienced by participants. A decreased feeling of social nearness under poor communication conditions appears to induce more task-oriented and formal cooperative behavior (Williams, 1977; Van der Velden, 1995). In particular the outcome of tasks with an ambiguous or equivocal character is expected to depend on the richness of the mediated communication condition (Short et al., 1976). Though researchers have predicted differences in task-outcome they have never been able to reveal them experimentally.

We have built experimental teleconferencing facilities to isolate the influence of isotropy on task-outcome and conversational interaction for a variety of tasks. The results indeed showed that mediated conditions influence task-outcome. People are more easily convinced of non-valid arguments under isotropic conditions (face-to-face and mediated isotropic) than under non-isotropic mediated conditions. Furthermore, people communicate almost twice as much unshared information and attach far more importance to group benefit under mediated conditions than under the face-to-face condition.

##### 4.1 Predictive power of the findings

The variety of tasks and communication conditions tested is only a subsample of the rich world of communication tasks and communication systems that will be of interest when new applications are developed in the near future. Therefore, when trying to generalize our findings, the limitations of the range of variables tested have to be taken into account. We'll discuss a few limitations in the following.

###### *Only discussion tasks were tested*

The tasks tested were selected on their potential to induce differences in conversational behavior and task-outcome under the different communication conditions. The tasks were characterized by a high level of equivocality and task-outcome will strongly depend on non-

verbal information (Short et al., 1976; Daft & Lengel, 1986; Morley & Stephenson, 1969; Williams, 1977). Tasks that a priori didn't rely on non-verbal information (video communication) were not selected. Generally only discussion tasks were considered in which non-verbal information was influential for conveying information (arguments). For formal, objective and relatively emotionless exchanges of information one may find only insignificant effects of communication conditions; calling each other by phone would be sufficiently effective for such tasks.

*Persuasive force was tested based on acted behavior*

The results of the Lost at the Moon task proved that persuasive force is influenced by isotropy under mediated conditions. For this purpose we have "exposed" participants to a standardized dominant behavior by an actor using pre-defined item lists and arguments. This way it became possible to objectively compare persuasive force between conditions. The obvious disadvantage of this method is that the results cannot be generalized beyond the typical dominant communication behavior of the single actor tested. It would be of interest to study a natural variety of dominant participants, perhaps revealing a correlation between measures of dominance of individual participants and the similarity of their individual solutions with the group solution.

*Tested groups were small (three participants)*

We have tested group tasks in which three participants discussed arguments to reach a group decision. Three participants is the smallest group for which gaze direction can play a role in regulating conversational behavior. Moreover, the number of cameras and monitors needed to realize isotropic conditions grows rapidly with the number (n) of participants and equals  $n(n-1)$ , unless techniques are used to derive one view from a set of others (Vetter & Poggio, 1995). However, it would be valuable to examine the role of gaze direction for larger groups in which the regulation of conversation becomes increasingly important.

*Participants didn't know each other*

The participants tested in our experiments had not met each other before. Consequently, participants had no a priori information about the social context or characters of fellow group members. The process of forming a group during the experiments started from scratch. This is unlike group work (meetings, discussions) of colleagues having a shared history of working together. Future research may reveal possible effects of mutual familiarity of participants.

*Is it good or bad?*

Whether we should label changes in task-outcome or conversational behavior due to mediated conditions as positive or negative depends entirely on what task-outcome is appreciated by the participants. For example, the increased individual resistance of listeners to non-valid

arguments under non-isotropic mediated conditions may not always be appreciated by a speaker if the success of his mission relies partly on non-verbal behavior. He may favor isotropic conditions. In general, the specifications of video-conferencing set-ups should be built on a thorough analysis of tasks and human communication processes. Evaluation of our findings will depend strongly on the intention of the users of mediated communication systems.

*Non-isotropy was confound with self-image*

As mentioned before, the non-isotropic video-conferencing set-up presented the images of all participants (including the self-image) in different quadrants on a single monitor. Consequently, the effects of non-isotropy and the visibility of the self-image were confound in the non-isotropic condition. Thus, a good question is whether the self-image (and not isotropy) was responsible for the significant differences in persuasive force observed in the Lost at the Moon task.

First, the list of comments given by participants after the experiments gives some indications that eye-contact and gaze-direction under isotropic video-conferencing was appreciated more than the fact that no self-image was presented. Only 12% of the comments showed a negative appreciation of the self-image under non-isotropic conditions, whereas 47% of the comments showed a negative appreciation of the fact that eye-contact and gaze-direction were not facilitated under that condition. Second, it appears that the presentation of the self-image did not have a significant influence on measures of conversational interaction under video-conferencing conditions (Sellen, 1995). Last, the high level of equivocality of the tasks selected for our experiments make it likely that non-verbal communication (gaze-direction) was the dominant factor in task-outcome (Short et al., 1976; Daft & Lengel, 1986; Morley & Stephenson, 1969; Williams, 1977).

*Differences in image quality*

Under mediated conditions, the resolution of the image of a person perceived is inherently lower than under face-to-face conditions: the number of pixels with which a face can be represented is finite. The spatial resolution of the image in our experiments was approximately 2.5 arcmin, clearly beyond the acuity (1 arcmin) of the human eye. Although participants subjectively reported to have no problems with recognizing facial expressions, we cannot exclude a better transfer of non-verbal visual information with higher image resolutions.

The resolution with which a face was represented in our experiments was approximately similar for non-isotropic and isotropic conditions. Also, the subtended angle of a person's face was similar under both mediated conditions and similar to the subtended angle under face-to-face conditions. Therefore we do not believe that differences in image quality can be responsible for the differences in performances as observed in our experiments.

#### 4.2 Future research

Because of the observed differences of communication behavior and task-outcome between conferencing conditions, one may eventually want to choose for isotropic conferencing set-ups when, for example, persuasive force is critical. However, it should be noted that isotropic set-ups go with higher expenses because more desk-space, cameras, monitors and bandwidth are required. Therefore, the added value for specific operational tasks should be evaluated before such a choice is made. For some tasks it may even be worthwhile to see if audio-only systems (no non-verbal information) may suffice.

We have isolated the role of isotropy and have not yet focussed, for example, on the optimal sizes, resolutions and update-frequencies of the images presented nor on the added value of colored images. All these properties determine the required bandwidth and are interesting variables to study in future experiments. Further, a very important variable is the delay between the actions of a person at one end of the line and the audio-visual representation of that person at the other end (transmission delay). Such transmission delays can seriously disturb interruption behavior and therefore the speed of communication, the quality of task-outcome and the user's appreciation of the medium. The role of image properties and of transmission delay are interesting topics for future research.

A last aspect that we haven't studied is the evolution in time of conversational behavior when participants are exposed to video-conferencing conditions for considerable longer time spans, say days, than the length of our experimental sessions. It cannot be excluded that the user's appreciation of a system and also the user's objective task performance changes over time while getting familiar with the system. During longer exposures and more regular use of video-conferencing facilities, users may adapt their conversational behavior to both the limitations and the opportunities of the system, eventually yielding other behavior than observed in our experiments. Aspects like team-building and group participation under different communication conditions should be studied in future research.

### 5 CONCLUSIONS

- The "Lost at the Moon" task (a group survival task) has revealed that *persuasive force* (the ability to change another person's opinion) is facilitated significantly more ( $p < 0.05$ ) by *isotropic* communication conditions (mediated or face-to-face) than by *non-isotropic* (mediated) conditions. *Dominance* (the ability to influence group solutions by dominant behavior) was similar for all conditions.

Furthermore, the observations of interactional behavior suggest that mediated conversation is less spontaneous, less interactive and less regulated than under face-to-face conditions.

- The results of the "Case of the fallen businessman" (a problem solving task) have shown that participants communicate significantly ( $p = 0.06$ ) more unshared information (almost twice as much) under mediated isotropic communication than under the face-to-face

condition. Further, the data strongly suggest a similar increase of information sharing under the non-isotropic condition. All together we conclude that video conferencing stimulates the exchange of *unshared information*. This finding is consistent with the findings that, under mediated conditions, participants felt more part of a team and experienced a *smaller* distance to other participants than under face-to-face conditions.

- The IG task (a management game) has revealed that people value *group benefits* (versus individual benefits) far more ( $p < 0.05$ ) under *mediated* conditions (isotropic and non-isotropic) than under *face-to-face* conditions.

One has to be careful with interpreting the current results and estimating the potential value and success of video-conferencing applications because we have studied generic tasks in lab-conditions. Furthermore, they do not cover the full range of tasks. Specific (business) applications should be evaluated thoroughly to reveal their bottle-necks and benefits.

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<p>The visual component of conversational media such as video-conferencing systems communicates important non-verbal information such as facial expressions, gestures, posture and gaze. Unlike the other cues, selective gaze depends critically on the configuration of cameras and monitors. Under isotropic video conferencing conditions people see each other in spatially consistent directions (shared video space). Isotropy is hypothesized to improve the interactional process of conversation and the outcome of discussion tasks compared to non-isotropic conditions.</p> <p>We have studied the interactional process and task outcome of a variety of discussion tasks under isotropic and (standard) non-isotropic video-conferencing conditions relative to face-to-face conditions. The communication of unshared information was tested in a murder-solving task called "The Case of the Fallen Businessman". Dominance and persuasive force were revealed using a prioritization game of survival items called "Lost at the moon", featuring a dominant actor. Further, we quantified emotional behavior and the trade-off between individual and group benefits in a "prisoner's dilemma"-like management game. The results support our hypotheses and have revealed that persuasive force (the ability to change another person's opinion) is significantly stronger under isotropic conditions (including face-to-face) than under non-isotropic conditions. In contrast, dominance (the ability to influence group solutions by dominant behavior) is similar for all conditions. Further, participants communicate almost twice as much unshared information and value group benefit far more under mediated conditions than under the face-to-face condition.</p>		
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